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Claims

1.   A method of producing an image containing depth
information, comprising:
5   detecting a radiation wavefield emanating from
the scene and taking at least two images of the scene at
different planes relative to the scene to produce a first
image comprised of a first set of intensity data values
and a second image comprised of a second set of intensity
10   data values;
              determining an intensity variation of data values
in the first set of data values relative to other data
values in the first set of data values to produce a first
set of intensity variances, and determining an intensity
15   variation of data values in the second set of values
relative to other data values in the second set of values
to produce a second set of intensity variance data;
              processing the first and second sets of intensity
variance data to obtain image data of the scene containing
20   depth information; and
              coding the image data which have the same depth
information with a code reference to identify the
different depth information in the image data.

25   2.   The method of claim 1 wherein the step of processing
the intensity variance data preferably comprises:
              (a)   producing a representative measure of the
rate of change of variance data values of said radiation
wave field over a selected surface extending generally
30   across the wave field;
              (b)   producing a representative measure of said
radiation wave field relating to the scene over said
selected surface;
              (c)   transforming said measure of rate of change
35   of variance to produce a first integral transform
representation and applying to said first integral
transform representation a first filter corresponding to

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the inversion of a first differential operator reflected
in said measure of rate of change of variance to produce a
first modified integral transform representation;

(d)   applying an inverse of said first integral
5   transform to said first modified integral transform
representation to produce an untransformed representation;

(e)   applying a correction based on said measure
over said selected surface to said untransformed
representation;

10   (f)   transforming the corrected untransformed
representation to produce a second integral transform
representation and applying to said second integral
transform representation a second filter corresponding to
the inversion of a second differential operator reflected
15   in the corrected untransformed representation to produce a
second modified integral transform representation;

(g)   applying an inverse of said second integral
transform to said second modified integral transform
representation to produce a measure of phase of said
20   radiation wave field across said selected plane so as to
produce said image data as phase image data containing the
depth information.

3.   The method of claim 2 wherein step of producing a
25   representative measure of said radiation wavefield
relating to the scene over the selected surface may use
intensity values to obtain the representative measure or
variance values.

30   4.   The method of claim 3 wherein intensity values at
the selected surface are used.

5.   The method of claim 3 wherein values are taken
representing maximum focus from any of the intensity data
35   values.

6.   The method of claim 3 wherein variance data

values are used as a representative measure.

7.   The method of claim 3 wherein maximum variance values taken from the sets of variance data values are used.

8.   The method of claim 1 wherein at least one of the first or second differential operator has a form based on an optical system used to acquire the radiation for producing the representative measure of the rate of change of variance of the radiation wavefield over the selected surface extending generally across the wavefield.

9.   The method of claim 8 wherein both the first and second differential operators have a form based on the optical system.

10.   The method of claim 2 wherein the first and second integral transforms are produced using a Fourier transform.

11.   The method of claim 2 wherein the differential operators have the form:

$$\frac{\sqrt{T_P}}{T_P + \alpha^2}$$

where,

$$T_P(\rho) = 2\pi i \delta z \int \eta T_P^{(3)}(\rho, \eta) d\eta$$

and

$$T_P^{(3)}(\rho,\eta) = \frac{i}{2\pi\rho}\left\{\begin{array}{l}\left[\left[\tfrac{1}{2}\rho_{obj}^2\left(\xi^2+1\right)-\tfrac{1}{4}\rho^2-\left(\frac{\eta}{\lambda\rho}\right)^2-\left|\frac{\eta}{\lambda}-\tfrac{1}{2}\rho_{obj}^2\left(\xi^2-1\right)\right|\right]^{\frac{1}{2}}\right. \\ \left.-\left[\tfrac{1}{2}\rho_{obj}^2\left(\xi^2+1\right)-\tfrac{1}{4}\rho^2-\left(\frac{\eta}{\lambda\rho}\right)^2-\left|\frac{\eta}{\lambda}+\tfrac{1}{2}\rho_{obj}^2\left(\xi^2-1\right)\right|\right]^{\frac{1}{2}}\end{array}\right\}$$

and wherein ρ is radial lateral spatial frequency, the η
longitudinal spatial frequency and δz is the defocus
distance in the plane of the object. Also

$$\xi = \frac{NA_{condensor}}{NA_{objective}}$$

where $NA_{condensor}$ and $NA_{objective}$ are respectively the numerical
aperture of the condenser and the objective (These are
settings and dimensions on the microscope). ρ_{obj} is the
maximum spatial frequency accepted by the objective.

12.   The method of claim 1 wherein the step of taking at
least two images of a scene comprises taking the first
image at a first defocused plane to produce the first
image as negatively focused image data and taking the
second image of the scene at a second defocused plane to
produce positive defocused image data, the negative and
positive defocused image being taken on respective sides
of a focal plane which would produce an in focus image of
the scene.

13.   The method of claim 1 wherein the step of determining
an intensity variance comprises determining a measure of
the sharpness of each of the data values relative to the
sharpness of data values surrounding that data value.

14.   The method of claim 1 wherein the images are captured
by a charge coupled device and an intensity value of
pixels in the image is determined, and that intensity
value is compared with the intensity of surrounding pixels
in order to provide a variance value at each pixel.

15.   The method of claim 14 wherein the variance is
obtained by the following equation for each pixel:

$$\text{var.}_n = \frac{1}{8} \times \sqrt{\begin{array}{l} (I_n - I_2)^2 + (I_n - I_4)^2 + (I_n - I_8)^2 \\ + (I_n - I_6)^2 + \frac{1}{\sqrt{2}}(I_n - I_1)^2 + \frac{1}{\sqrt{2}}(I_n - I_3)^2 \\ + \frac{1}{\sqrt{2}}(I_n - I_7)^2 + \frac{1}{\sqrt{2}}(I_n - I_9)^2 \end{array}}$$

wherein n is the particular pixel, and the values 1 to 9 represent the pixels which surround that pixel in an array of pixels.

16.   The method of claim 1 wherein the step of coding parts of the image data comprises applying different colours to parts of the image which have the same depth information so as to produce a visual image in which the relative distance of parts of the scene compared to one another can be determined.

17.   The method of claim 1 wherein a third image of the scene is taken at an in focus plane to produce a third set of intensity data values and the third set of intensity data values are overlaid with the coded image data to produce a visual image containing structural information of the scene as well as the different depth information in the scene.

18.   The method of claim 15 wherein the different depth information is provided by allocated a grey scale value to pixel values in the image.

19.   An apparatus for producing an image containing depth information comprising:
         a camera for detecting a radiation wavefield emanating from a scene and taking at least two images of the scene at different planes relative to the scene to produce a first set of intensity data values and a second set of intensity data values;
         a processor for determining an intensity variation of data values in the first set of data values

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compared to other data values in the first set of data
values to produce a first set of variance data values, and
for determining a variance of one data value in the second
set of data values compared to other data values in the
5   second set of data values to produce a second set of
variance data values;
        the processor also being for processing the first
and second variance data values to produce image data of
the scene containing depth information; and
10   the processor also being for coding parts of the
image which have the same depth information with a code
reference to identify the different depth information in
the image.

15   20.   The apparatus of claim 19 wherein the processor for
determining an intensity variation is a processor for:
        (a)   producing a representative measure of the
rate of change of variance data values of said radiation
wave field over a selected surface extending generally
20   across the wave field;
        (b)   producing a representative measure of said
radiation wave field relating to the scene over said
selected surface;
        (c)   transforming said measure of rate of change
25   of variance to produce a first integral transform
representation and applying to said first integral
transform representation a first filter corresponding to
the inversion of a first differential operator reflected
in said measure of rate of change of variance to produce a
30   first modified integral transform representation;
        (d)   applying an inverse of said first integral
transform to said first modified integral transform
representation to produce an untransformed representation;
        (e)   applying a correction based on said measure
35   over said selected surface to said untransformed
representation;
        (f)   transforming the corrected untransformed

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representation to produce a second integral transform
representation and applying to said second integral
transform representation a second filter corresponding to
the inversion of a second differential operator reflected
5   in the corrected untransformed representation to produce a
second modified integral transform representation;
        (g)   applying an inverse of said second integral
transform to said second modified integral transform
representation to produce a measure of phase of said
10   radiation wave field across said selected plane so as to
produce said image data as phase image data containing the
depth information.

        21.   The apparatus of claim 20 wherein at least one of
15   the first or second differential operator has a form based
on an optical system used to acquire the radiation for
producing the representative measure of the rate of change
of variance of the radiation wavefield over the selected
surface extending generally across the wavefield.
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        22.   The apparatus of claim 21 wherein both the first
and second differential operators have a form based on the
optical system.

25   23.   The apparatus of claim 22 wherein the first and
second integral transforms are produced using a Fourier
transform.

        24.   The apparatus of claim 21 wherein the
30   differential operators have the form:

$$\frac{\sqrt{T_P}}{T_P + \alpha^2}$$

where,
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$$T_P(\rho) = 2\pi i \delta z \int \eta T_P^{(3)}(\rho, \eta) d\eta$$

and

$$T_P^{(3)}(\rho,\eta) = \frac{i}{2\pi\rho} \left\{ \begin{array}{l} \left[\tfrac{1}{2}\rho_{obj}^2 \left(\xi^2 + 1\right) - \tfrac{1}{4}\rho^2 - \left(\dfrac{\eta}{\lambda\rho}\right)^2 - \left|\dfrac{\eta}{\lambda} - \tfrac{1}{2}\rho_{obj}^2 \left(\xi^2 - 1\right)\right| \right]^{\frac{1}{2}} \\[2em] - \left[\tfrac{1}{2}\rho_{obj}^2 \left(\xi^2 + 1\right) - \tfrac{1}{4}\rho^2 - \left(\dfrac{\eta}{\lambda\rho}\right)^2 - \left|\dfrac{\eta}{\lambda} + \tfrac{1}{2}\rho_{obj}^2 \left(\xi^2 - 1\right)\right| \right]^{\frac{1}{2}} \end{array} \right\}$$

and wherein ρ is radial lateral spatial frequency, the η longitudinal spatial frequency and δz is the defocus distance in the plane of the object. Also

$$\xi = \frac{NA_{condensor}}{NA_{objective}}$$

where $NA_{condensor}$ and $NA_{objective}$ are respectively the numerical aperture of the condenser and the objective (These are settings and dimensions on a microscope, if a microscope is used in the capture of the various images by camera). ρ_{obj} is the maximum spatial frequency accepted by the objective.

25.   The apparatus of claim 19 wherein the images are captured by a charge coupled device and an intensity value of pixels in the image is determined, and that intensity value is compared with the intensity of surrounding pixels in order to provide a variance at each pixel.

26.   The apparatus of claim 25 wherein the variance is obtained by the following equation for each pixel:

$$\mathrm{var.}_n = \frac{1}{8} \times \sqrt{ \begin{array}{l} (I_n - I_2)^2 + (I_n - I_4)^2 + (I_n - I_8)^2 \\[0.5em] + (I_n - I_6)^2 + \dfrac{1}{\sqrt{2}}(I_n - I_1)^2 + \dfrac{1}{\sqrt{2}}(I_n - I_3)^2 \\[0.5em] + \dfrac{1}{\sqrt{2}}(I_n - I_7)^2 + \dfrac{1}{\sqrt{2}}(I_n - I_9)^2 \end{array} }$$

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wherein n is the particular pixel, and the values 1 to 9
represent the pixels which surround that pixel in an array
of pixels and I is the intensity value of the respective
pixel.

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27.   The apparatus of claim 26 wherein the processor
is for applying different colours to parts of the image
which have the same depth information so as to produce a
visual image in which the relative distance of parts of
10   the scene compared to one another can be determined.

28.   The apparatus of claim 27 wherein the different
depth information is provided by allocated a grey scale
value to pixel values in the image.

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